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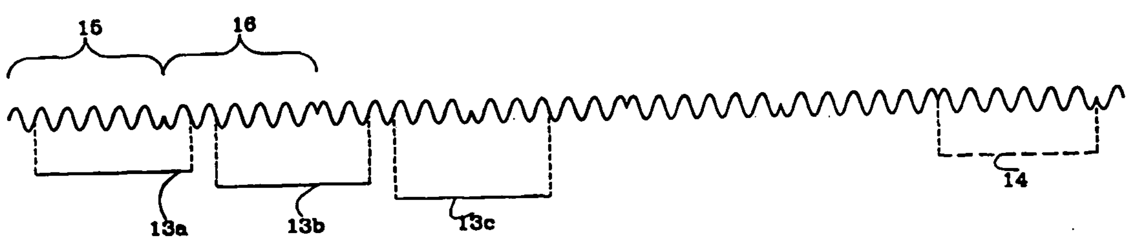

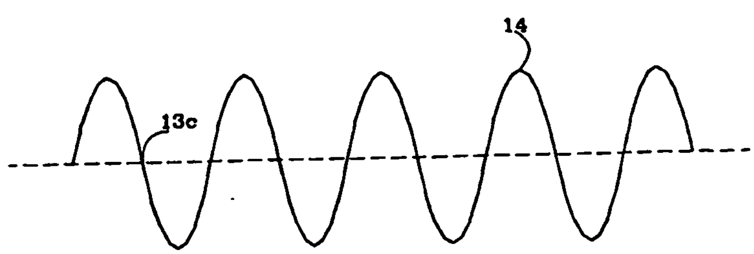

(57) Abstract

The present invention concerns a method and a device for the synchronization of a transmitter (1) and at least one receiver (3) in multi-carrier modulated communication systems in which FFT technology is used for the modulation and demodulation of data transmitted between the transmitter (1) and the receiver (3). According to the invention the transmitter (1) transmits synchronization symbols (15, 16) as training symbols (15, 16) at the beginning of a transmission, until a result is obtained that may indicate where a synchronization symbol starts. The result is used for the adjustment of the symbol rate in the receiver (3). Data symbols may then be transmitted after the

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METHOD AND DEVICE IN A COMMUNICATION SYSTEM

TECHNICAL FIELD

The present invention relates to a method and a device for recovery of sampling rate and symbol rate in multi-carrier modulated communication systems, preferably using copper wires as a transmission medium.

STATE OF THE ART

Multi-carrier modulation is a known method for transmitting broadband information over copper wire or radio connections. The information may be, for example, video, Internet or telephony. Very briefly explained, for example, the bits of a digitally encoded video signal that are to be transmitted, are encoded as complex numbers in a transmitter, before an Inverse Fast Fourier Transform (IFFT) is carried out.

The IFFT gives, in the modulation, a sum of orthogonal carriers or tones, the amplitudes and phase displacement of which are determined by the values and phases of the complex numbers. These carriers are then transmitted in time slots at constant time intervals and are called symbols. In a receiver a Fast Fourier Transform (FFT) is carried out instead. In this way, the original bits are retrieved. Attenuation and phase displacement may be easily compensated for, by multiplication by a complex number for each carrier.

Two similar methods in the above mentioned technology are Orthogonal Frequency Division Multiplex (OFDM), used in radio applications, and Discrete Multitone (DMT), which is used in copper wires.

In both cases the receiver must be able to adjust the correct sampling rate and to determine the beginning and the end of the transmitted symbols.

In WO 95/03656 OFDM is used. To adjust the symbol rate, a transmitter transmits synchronization frames at known intervals, that is, synchronization symbols having a pseudo random sequence of known frequencies and phase displacements, and also known time intervals in special time slots. The receiver carries out a number of FFT calculations over the position in time in which the synchronization frame is presumed to be found. For each FFT calculation a cross correlation calculation is made in the frequency plane, using the known frequency function of the synchronization frame. The correlation maximum is detected, which determines the time slot containing the synchronization frame.

SUMMARY OF THE INVENTION

The problem associated with transmitting synchronization symbols at known intervals is that it takes up time in which data could have been transmitted. Also, a complex procedure of cross correlation calculations is required to detect and analyze the synchronization symbols.

The object of the present invention is to solve the above problem by transmitting training symbols before the start of a data transmission. Each training symbol comprises at least a period of a pilot tone and is transmitted using 180° phase jumps between the symbols. The use of this simple training symbol makes it easy to detect the beginning and the end of the symbol. An FFT calculated over the length of a symbol gives the value zero at a maximally erroneous position, that is, with the phase jump in the middle of the calculation, and a maximum/minimum at the ideal position, that is, half way between two phase jumps. The simplest method is probably to look for the position in which the result of the FFT calculation is zero and then move a distance of half a symbol.

An advantage of the present invention is that the symbol rate may be restored in a fast and simple way even before the beginning of a data transmission. During the

transmission it may then be sufficient to use a method known in the art for retrieving the sampling rate, because if something locks the sampling rate, the symbol rate is automatically kept constant. Another advantage is that the inventive method is simple and inexpensive to implement.

The invention will be described in more detail in the following, by means of preferred embodiments and with reference to the enclosed drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a block diagram of a prior art system for multi-carrier modulation.

Figure 2a is a timing diagram of the restoration of the symbol rate according to the invention.

Figure 2b is a timing diagram of the result of the FFT calculations according to Figure 2a.

Figure 3 is a block diagram of an embodiment of the restoration of the symbol rate according to the invention.

Figures 4a, 4b and 4c are timing diagrams of the restoration of the sampling rate according to the invention.

Figure 5 is a block diagram of an embodiment of the restoration of the sampling rate according to the invention.

PREFERRED EMBODIMENTS

Multi-Carrier Modulation

Figure 1 shows, schematically, how the main parts of a prior art system for multi-carrier modulation may look. In a transmitter 1 modulation of data bits, for example, from a digitally encoded video signal, is performed.

The bits to be transmitted are encoded in the transmitter 1 as N complex numbers before a hermit symmetry operation is carried out in a calculation block 4. 2N complex numbers are obtained having a symmetric real part and an asymmetric imaginary part.

An Inverse Fast Fourier Transform (IFFT) is then performed in an IFFT calculation unit 5, as a modulation. As the imaginary part becomes zero, it may be eliminated, and a real signal remains, which passes a parallel to serial converter 6 and a digital to analogue converter 7.

This gives a sum of orthogonal carriers or tones, the amplitudes and phases of which are determined by the values and phases of the original complex numbers. These carriers are then transmitted on a channel 2 at constant time intervals/time slots and are called symbols.

In a receiver 3 the data, in the opposite way, passes an analogue to digital converter 8, a serial to parallel converter 9 and an FFT calculation unit 10, in which an FFT is carried out, as a demodulation. This gives 2N complex numbers. For symmetry reasons, for example, the upper half of the 2N complex numbers may be discarded, leaving a number N of complex numbers.

Finally, an equalizer 11 is used, which compensates for attenuation and phase displacement by multiplying the different numbers with complex numbers so that finally the same data bits are obtained that were transmitted to begin with.

For each new symbol a discontinuity occurs in the carriers. To minimize the effects of this a so called cyclic prefix (not shown in the figure) may be used. This means copying the last part of the symbol and transmitting it just before the start of the symbol. In this way there is time for the effect of the discontinuity to fade out before the actual symbol starts.

Symbol Rate

In order to synchronize the transmitter 1 and the receiver 3, according to the invention first the sampling rate is adjusted so that the transmitter 1 and the receiver 3 sample at approximately the same times and so that the first sample taken is approximately zero. This will be described in more detail later.

Then training symbols are transmitted so that the receiver 3 will know where data symbols transmitted later will begin and end. It is appropriate to transmit the training symbols only at the beginning of the transmission. During transmission it may then be sufficient to use some method known in the art for restoration of the sampling rate, since if the sampling rate is locked the symbol rate is automatically maintained.

When both the sampling rate and the symbol rate have been restored, the transmitter 1 and the receiver 3 are synchronized and the data transmission may begin.

Figure 2a shows a training symbol 15 which, according to the invention, is used to restore the symbol rate. The training symbol 15 comprises a number of periods of a pilot tone or carrier, in this case, for the sake of illustration, six periods. This train-

ing symbol 15 is transmitted with a 180° phase jump for each new symbol so that every other symbol 16 is inverted.

To detect the symbol position a series of time shifted FFT calculations 13a, 13b, 13c are carried out during a time interval of the same length as a training symbol according to Figure 2a or in a similar way. The result of the FFT calculations 13a, 13b, 13c will then vary approximately as shown in Figure 2b. The maximum and the minimum, respectively, of the result in Figure 2b is achieved when the FFT calculation 14 in Figure 2a is carried out exactly on a symbol or an inverted symbol, respectively, that is, in the desired position.

The maximum or minimum may, however, be difficult to detect. It is considerably less difficult to detect when the FFT calculation 13c is totally wrong, as the result then becomes zero. The most appropriate solution may therefore be to time shift the FFT calculations 13a, 13b, 13c until a value relatively close to zero is calculated and then indicate the start of a symbol half a symbol away from this.

Note that if a cyclic prefix is used, this must be accounted for. Depending on the direction in which it is desired to move to find the start of the symbol, either the distance moved should be half a symbol, as usual, or half a symbol plus the length of the cyclic prefix.

An example of the implementation of the embodiment for looking for the point where the FFT calculation becomes zero, is shown, schematically, in Figure 3. The data sampled in the receiver is successively shifted into a shift register 21 or a similar set of memory units. From there, at different time intervals as shown below, parallel data corresponding to the length of a symbol is read to a calculation unit 22 in which an FFT calculation of the parallel data, for example 1024 points, is carried out.

The result of the FFT calculation is then placed in a register 23, from which data corresponding to the frequency of the phase jumping pilot tone may be retrieved in one of the memory positions 23a.

This data is forwarded to a calculation block 24, in which the imaginary component of the frequency of the pilot tone is preferably obtained for future adjustment to zero. During every other symbol the sign of the imaginary component is changed, or only every other symbol is calculated. This is done because every other symbol is inverted.

The imaginary component adjusted in this way is compared to a threshold value. If the value of the adjusted imaginary component is smaller than or equal to the threshold value, the calculation block 24 emits a check value k equal to zero as the phase jump is then located approximately in the middle of the data on which the FFT calculation was carried out

If the adjusted imaginary part is greater than the threshold value, the calculation block 24 emits a check value, which may suitably be equal to the number of samples in a period of the pilot tone, for example, four. If, on the other hand the adjusted imaginary part is smaller than the negative threshold value, the calculation block 24 in a corresponding way emits a check value k, which is, in this case minus four.

The check value k is forwarded to a counter 25 which controls when the calculation unit 22 is to perform a new FFT calculation. If the number of samples is 1024, then the counter 25 counts down from 1023+k to zero, where k is the check value. This causes the successive shifting of the start position of the FFT calculation until the phase jump is located approximately in the middle of the samples that were subjected to the FFT calculation. This may be compared to the successive FFT calcula-

tions 13a, 13b and 13c in Figure 2a where each symbol, for clarity, only comprises 6*4=24 samples.

The symbol start needs then only be moved half a symbol to find the optimal position for the reading of the data to be transmitted.

Sampling Rate

Before the symbol rate is adjusted the sampling rate should be adjusted. The simplest way to do this is to use one of the carriers as a pilot tone, that is, transmitting a constant tone all the time, while the receiver locks to this tone.

Figures 4a-4c show an example in which the transmitter transmits a pilot tone with four samples 21a, 21b, 21c, 21d for each period and where the receiver, in the same way, reads the pilot tone with four samples 22a, 22b, 22c, 22d for each period.

In order to synchronize the transmitter and the receiver, for every four samples one, for example sample 22a, is taken out as a first sample in the receiver. The receiver then tries to adjust the sampling of the first sample 22a so that it takes place the first time the pilot tone passes zero. If the first sample 22a is positive, the sampling is shifted, so that the first sample 22a is taken a little earlier next time, see Figure 4a. If, on the other hand, the sample 22a is negative, the sampling is shifted so that the sample 22a is taken a little later next time, see Figure 4b.

The final, desired, result is shown in Figure 4c, in which the samples 21a, 21b, 21c, 21d and 22a, 22b, 22c, 22d of the transmitter and the receiver, respectively, are transmitted and received at approximately the same time.

Instead of the pilot tone a phase jumping pilot tone is then transmitted as training symbols as described above. In order for the adjustment of the receiver not to

change directions for every other symbol, the receiver instead locks to the phase jumping pilot tone. The simplest way to achieve this is probably by adjusting the sign of the first sample 22a with the sign of a second sample 22b before or after the first sample 22a, for example, at a distance of a quarter of a period. The second sample 22b will change signs for every other symbol, which will give an indication as to whether the pilot tone being sampled is inverted or non-inverted.

Figure 5 shows, schematically, how the above may be achieved in practice. In the receiver there is a voltage controlled oscillator (VCO) 31 controlling an analogue to digital converter 35 to take a first sample 22a that is delayed in a delay circuit 32, and a second sample 22b. The sign of the second sample 22b is identified and ”multiplied” with the first sample 22a in a sign correction unit 33. Of course, no real multiplication is needed; only the sign is changed, if necessary.

The sign correction unit 33 emits a control signal Q which passes a digital to analogue converter 34 and then controls the sampling through the oscillator 31 in the way described above.

Of course it is possible to instead delay the second sample 22. Then it is necessary to ”multiply”, in a corresponding way, the first sample 22a by the reverse sign of the second sample 22b.

During Data Transmission

The above method functions as a ”training” before the transmission of data. Of course it would be possible to interrupt the data transmission from time to time at known intervals to transmit training symbols again, but it would probably be better to use a known method for the retrieval of sampling rate, for example in the frequency domain, at least if the data is to be transmitted over copper wires. If the

sampling rate is locked the symbol rate will be maintained automatically. The time may then be used to transmit data symbols instead of training symbols.

These frequency domain techniques are usually slower than the method described above, but when the data transmission begins, approximately the correct sampling rate and symbol rate have already been adjusted, so that no major adjustments will be needed.

CLAIMS

1. A method for the synchronization of a transmitter (1) and at least one receiver (3) in multi-carrier modulated communication systems, in which FFT technology is used for the modulation and demodulation of data transmitted between the transmitter (1) and the receiver (3), **characterized** in that it comprises the following steps:

- the transmitter (1) transmits synchronization symbols (15, 16) at the beginning of a transmission, as training symbols (15, 16);

- the receiver (3) performs a series of time shifted FFT calculations on the synchronization symbols (15, 16) during time intervals the length of a synchronization symbol, until a result is achieved to give an indication of where a synchronization symbol (15, 16) starts, and

- the result is used for the adjustment of the symbol rate in the receiver (3),

- whereupon the transmitter (1) can transmit data symbols after the synchronization symbols (15, 16).

2. A method according to claim 1, **characterized** in that the synchronization symbols (15, 16) each comprises at least one period of a pilot tone and that the transmitter (1) transmits the synchronization symbols (15, 16) with an 180° phase jump between them.

3. A method according to claim 2, **characterized** in that the FFT calculation is ended when a maximum or minimum has been found, at which point the start of the synchronization symbol (15, 16) substantially coincides with the beginning of the time interval.

4. A method according to claim 2, **characterized** in that the FFT calculation is ended when the FFT calculation becomes substantially zero, at which point the start of the synchronization symbol (15, 16) substantially coincides with the middle of the time interval.

5. A method according to any one of the claims 2-4, **characterized** in that the sampling rate is adjusted before the adjustment of the symbol rate, by the receiver (3) locking to a simple pilot tone transmitted from the transmitter (1),

and that during the adjustment of the symbol rate, the sampling rate is adjusted by the receiver (3) locking to the phase jumping pilot tone transmitted from the transmitter (1).

6. A method according to claim 5, **characterized** in that after a sample has been taken when the pilot tone passes zero, a control signal is modified for the locking to the phase jumping pilot tone with the sign of an earlier or a later sample.

7. A device for the synchronization in multi-carrier modulated communication systems, comprising a transmitter (1) and at least one receiver (3), said transmitter (1) comprising an IFFT calculation unit (5) for modulation of data and said receiver comprising an FFT calculation unit (10) for demodulation of data, **characterized** in that

- the transmitter (1) is arranged to transmit synchronization symbols (15, 16) at the beginning of a transmission as training symbols (15, 16),

- the receiver (3) is arranged to perform a series of time shifted FFT calculations over the synchronization symbols (15, 16) during time intervals the length of a syn-

chronization symbol, until a result is obtained to indicate the start of a synchronization symbol (15, 16),

- the transmitter (1) may then be arranged to transmit data symbols after the synchronization symbols (15, 16).

8. A device according to claim 7, **characterized** in that the synchronization symbols (15, 16) each comprises at least one period of a pilot tone and that the transmitter (1) is arranged to transmit the synchronization symbols (15, 16) with 180° phase jumps between them.

9. A device according to claim 8, **characterized** in that the receiver (3) comprises an FFT calculation unit (22) connected to a shift register (21) for shifting sampled data and a counter (25) for controlling when the FFT calculation unit (22) is to retrieve sampled data from the shift register (21) for calculation and a register (23) for the temporary storing of calculated data, said register (23) being connected to a calculation block (24) which is connected to the counter (25).

10. A device according to any one of the claims 8-9, **characterized** in that the receiver (3) is arranged to adjust the sampling rate before the adjustment of the symbol rate, by locking to a simple pilot tone which the transmitter (1) is arranged to transmit,

and that the receiver (3) is arranged to adjust the sampling rate during the adjustment of the symbol rate by locking to the phase jumping pilot tone which the transmitter (1) is arranged to transmit.

11. A device according to claim 10, **characterized** in that the receiver (3) comprises a voltage controlled oscillator (31) arranged to control a taking of two samples (22a, 22b) at different points in time,

and a sign correcting unit (33) arranged to emit a control signal (Q) to control the oscillator (31) in dependence of one sample (22a) adjusted with the sign of the other sample (22b).

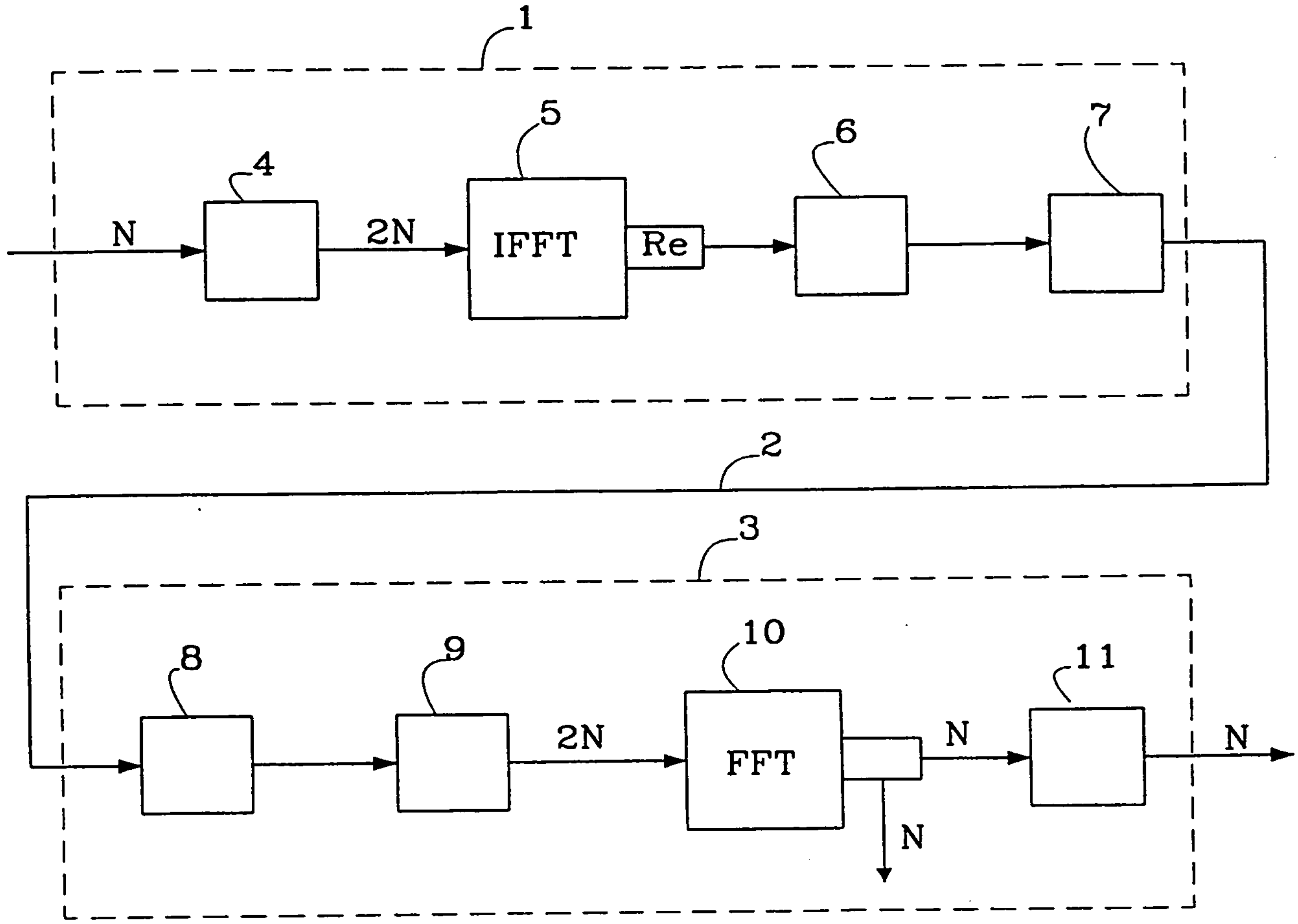

Fig 1

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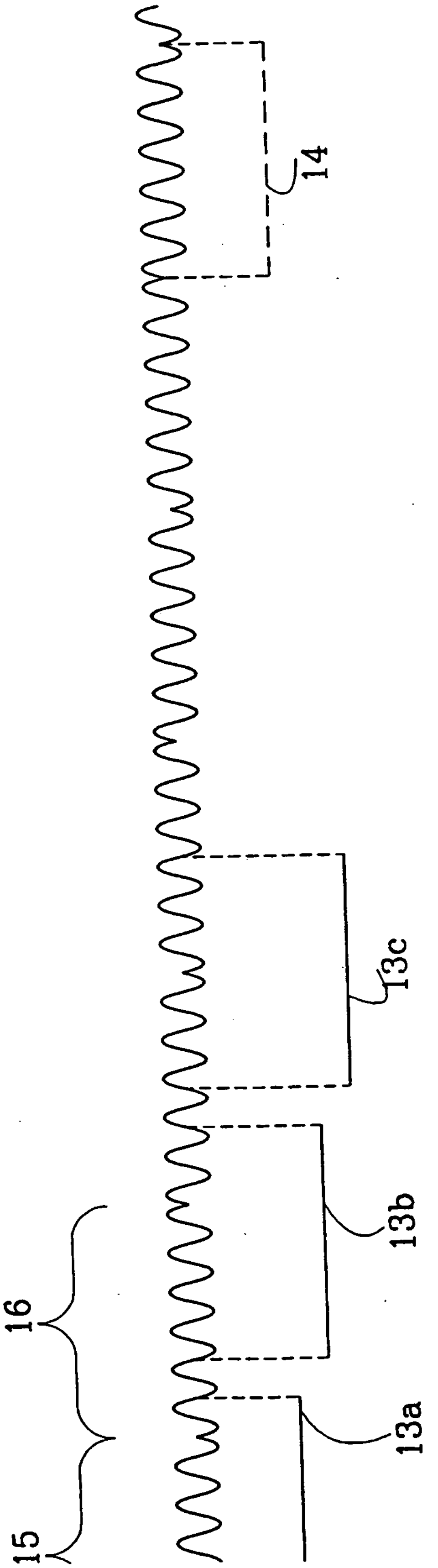

Fig 2a

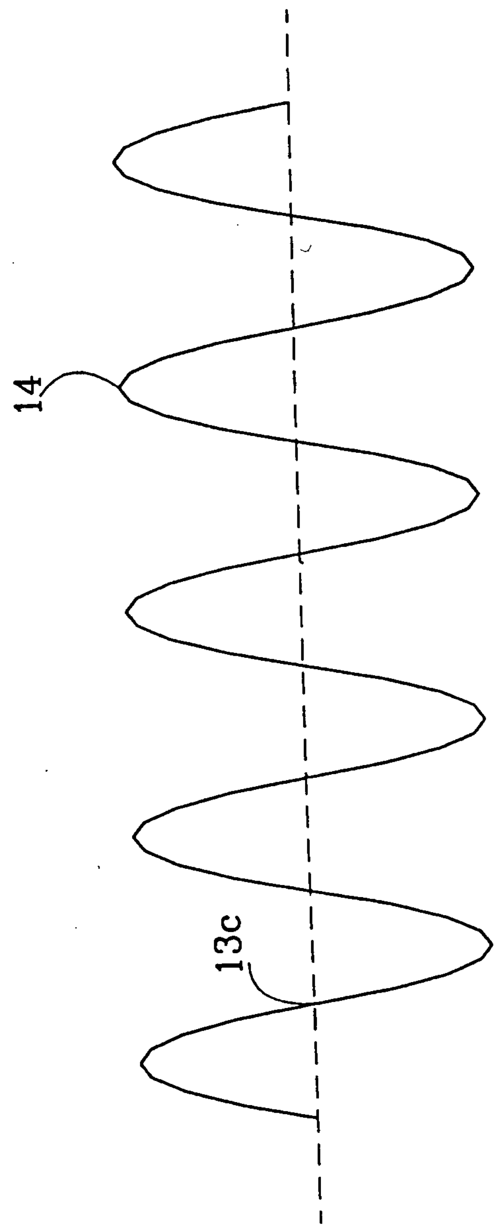

Fig 2b

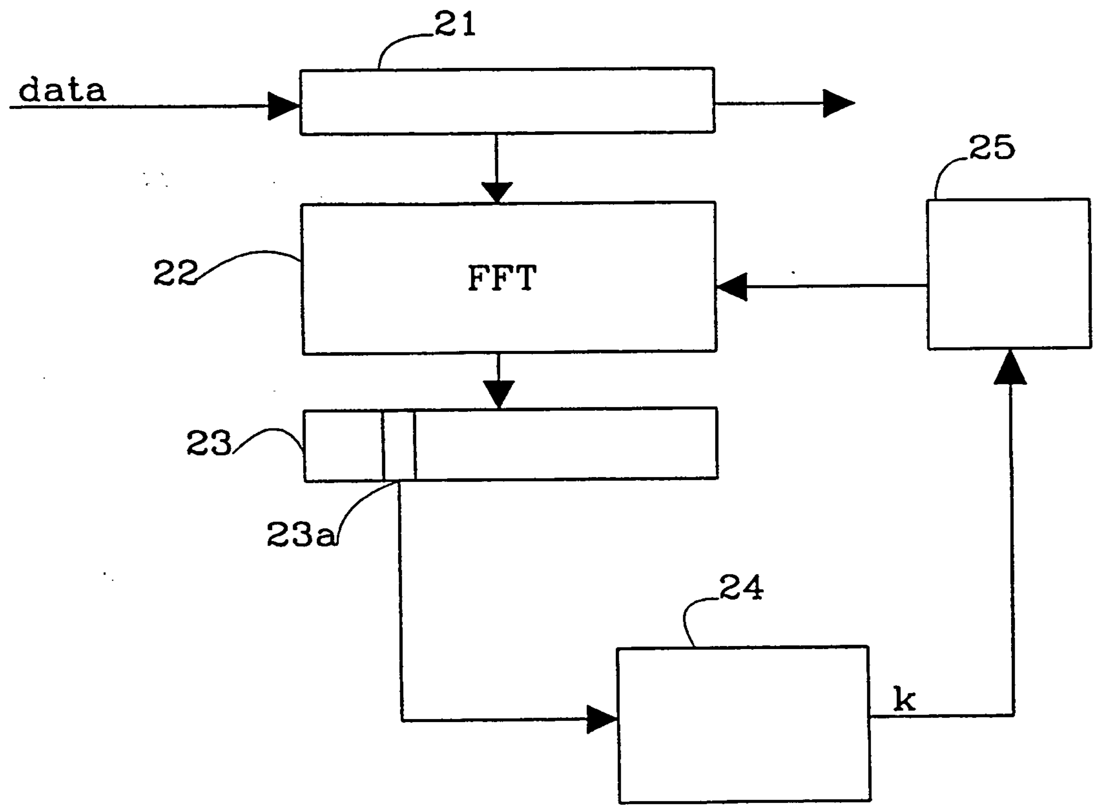

FIG 3

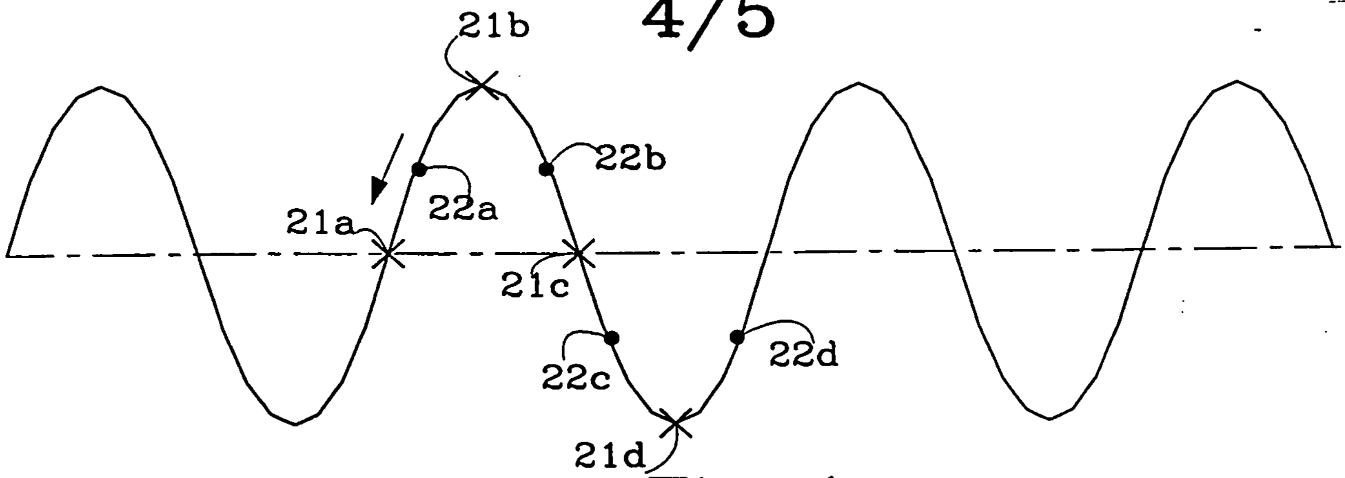

Fig 4a

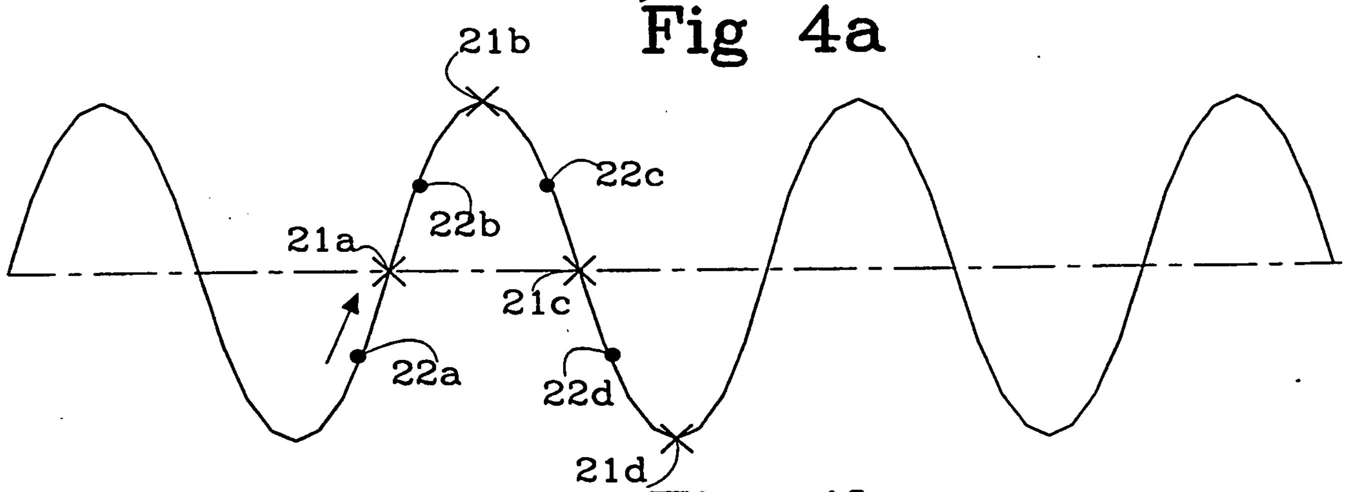

Fig 4b

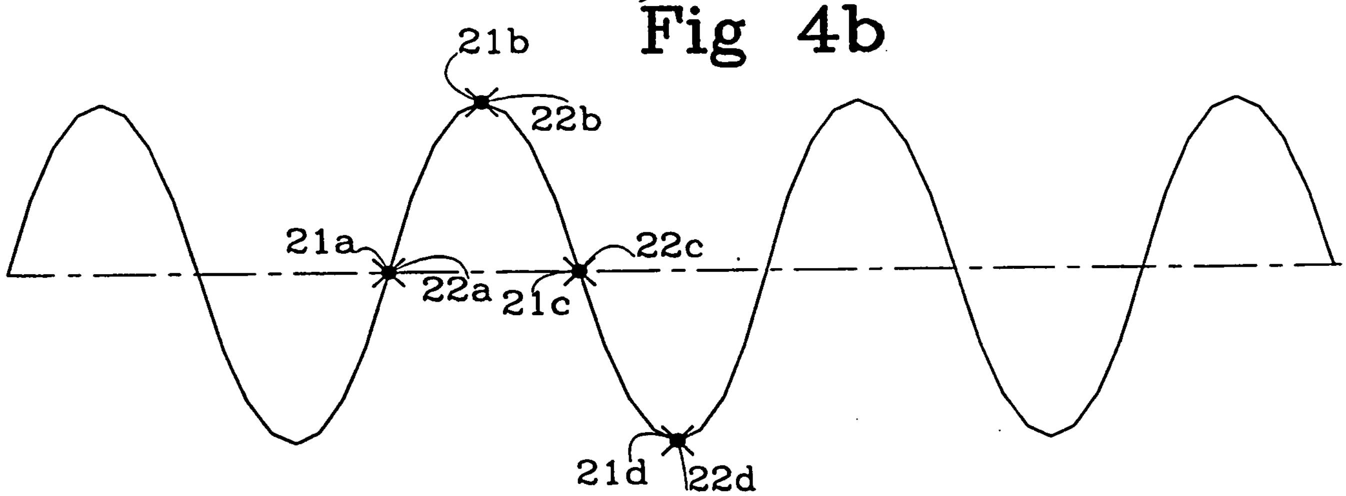

Fig 4c

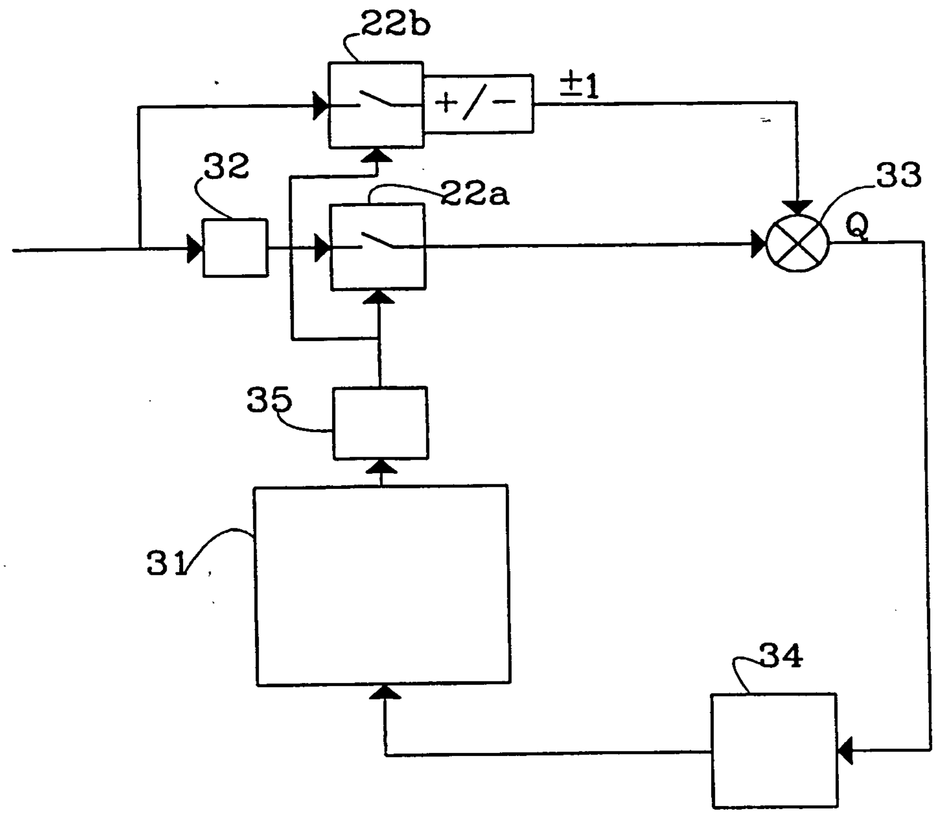

Fig 5